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ACID MINE DRAINAGE AND SUBSIDENCE: EFFECTS OF INCREASED COAL UTILIZATION

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

The Committee on Health and Ecological Effects of Increased Coal Utilization requested from the Environmental Protection Agency several status reports describing environmental impacts of increased coal production. The Industrial Environmental Research Laboratory-Cincinnati was requested to prepare a paper discussing the impact of acid mine drainage and subsidence. This report is that effort. In total, eleven papers were produced for the Committee, which reviewed the issues and prepared a report of their findings to the President. Further information on the Committee report can be obtained from Dr. David Rall, Chairman, Committee on Health and Ecological Effects of Increased Coal Utilization, National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina 27709.

For further information on the report contact the Resource Extraction and Handling Division.

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ABSTRACT

The increases above 1975 levels for acid mine drainage and subsidence for the years 1985 and 2000 based on projections of current mining trends and the National Energy Plan are presented. No increases are projected for acid mine drainage from surface mines or waste since enforcement under present laws should control this problem. The increase in acid mine drainage from underground mines is projected to be 16 percent by 1985 and 10 percent by 2000. The smaller increase in 2000 over 1985 reflects the impact of the PL 95-87 abandoned mine program. Mine subsidence is projected to increase by 34 and 115 percent respectively for 1985 and 2000. This estimate assumes that subsidence will parallel the rate of underground coal production and that no new subsidence control measures are adopted to mitigate subsidence occurrence.

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SECTION 1

EXECUTIVE SUMMARY

ACID MINE DRAINAGE

One of the most damaging waterborne contaminants from coal mining operations is the acid generated from the exposure of iron sulfide minerals found in some coal and overburden. Not only does the acid directly impact stream biota, eat away metal structures and destroy concrete, but as a result of the low pH, other ions such as heavy metals, become solubilized and carried into water courses. These ions are often toxic to aquatic life and render the water unusable for domestic and industrial use. In 1969, it was estimated that in excess of 10,000 miles of streams had been degraded by acid mine drainage. Water pollution control legislation and regulations, adopted by both federal and state governments since the initial survey was made, have resulted in a significant improvement in water quality where active mines are operating. Mine operators are treating acid mine drainage emanating from active mines in compliance with legal requirements. But because active and abandoned mines are located, in some instances, adjacent to each other, or discharge into the same stream, the overall improvement in water quality in those areas has not been as significant. The amount, and rate of acid formation, and the quality of water discharged are a function of the amount and type of pyrite in the overburden rock and coal, time of exposure, characteristics of the overburden, and the amount of available water.

Acid mine drainage is a unique pollutant, because acid generation and discharges continue to occur after mining has ceased. Underground mines contribute over 70 percent of the acid mine drainage. Inactive mines contribute a significant amount. The acid mine drainage problem is essentially a regional one. Most of the problem lies in the Appalachian Region (Federal Regions 3, 4, and 5), but acid discharges are found in the Interior Region in the states of Indiana, Illinois and Western Kentucky. Except for some isolated situations, acid mine drainage is not a problem in the western states.

Of the 21 coal producing states, all but two have some form of a law to control environmental damages from surface mining. The degree of control afforded by these laws and regulations vary drastically from state to state. However, the passage of the Surface Mining Control and Reclamation Act of 1977, PL 95-87, on August 3, 1977, will result in federal environmental standards for the the extraction of coal from surface mines and also set standards for the surface effects of underground mining. These regulations will go into effect in February 1978. Many of the provisions of the Act and the subsequent regulations will result in the control and reduction of acid mine drainage. State and federal laws for the control of acid discharges from inactive underground and surface mines have not been enacted. However, PL 95-87 establishes an abandoned mine reclamation fund and program, which should reduce the backlog of acid mine drainage producing situations.

SUBSIDENCE

The mining of a substantial quantity of underground material such as coal creates a void which in turn often produces a condition of instability within the rock leading to collapse of the overlying rock into the void and frequently associated surface subsidence. The condition may occur during the conduct of the mining operation or may not occur until many years after mining has been completed as the pillars slowly decay to the critical failure point.

Earth movements at the surface may result in many varied types of damage. Buildings are more severely affected by the compressive and extensive strains associated with subsidence than they are by the actual settlement. Highways, bridges, water and gas lines may be sheared, twisted or broken by strains and slope changes produced by subsidence. Sewage lines are especially susceptible to changes of slope that locally reverse their direction of flow. Effects upon the natural environment can also be quite dramatic. Natural drainage patterns can be changed resulting in formation or occasional destruction of swamps. Surface streams often are intercepted by subsided areas or induced rock fractures resulting in flow into deep mines and loss of surface waters. In severe cases groundwater supplies may be intercepted and drained into underlying deep mines. No definitive national analysis of the amount of land affected by past mine subsidence or of the annual or total property damage has been made.

Although methods exist to permit mining of a portion of the coal under developed areas without inducing subsidence, it is not likely that mine operators will voluntarily abandon a large percentage of their mineral resource unless they are required to provide surface support. If the mine operator must provide surface support then approximately 50 percent of the mineral must be abandoned which raises a key policy issue in terms of meeting the Nation's energy needs.

If no actions are taken by the Federal or State governments to control subsidence problems from future mining, then it is likely that present problems will be compounded and eventually remedial action will become necessary by government agencies. Only one state, Pennsylvania, has enacted legislation specifying the separate responsibilities of surface owners and mine operators for subsidence damage.

Projections

Table 1 provides estimates of the increases above 1975 levels for acid mine drainage and subsidence for the years 1985 and 2000 based on projections of current mining trends and the National Energy Plan. No increases are projected for acid mine drainage from surface mines or mine waste since enforcement under present laws should control this problem. The increases in acid mine drainage from underground mines and increases in mine subsidence will be

felt principally in Regions 3, 4, and 5 with negligible increases expected in other regions. The smaller increase in acid mine drainage in 2000 over 1985 reflects the impact of the PL 95-87 abandoned mine program.

TABLE 1. ESTIMATED INCREASE IN ACID MINE DRAINAGE AND SUBSIDENCE FOR THE YEARS 1985 and 2000 EXPRESSED AS PERCENT INCREASE ABOVE 1975 LEVEL

	Acid Mine Drainage		Subsidence	
	1985	2000	1985	2000
Surface Mines				
Pre-NEP	0(a)	0(a)	--	--
NEP	0(a)	0(a)	--	--
Mine Waste				
Pre-NEP	0(a)	0(a)	--	--
NEP	0	0		
Underground Mines				
Pre-NEP	16(b)	10(d)	48(c)	82(c)
NEP	16(b)	10(d)	34(d)	115(c)

(a) May be decreased as a result of PL 92-500 and PL 95-87.
(b) Includes inactive mines.
(c) May be substantially reduced if subsidence control measures are adopted.
(d) Includes inactive mines - reflects impact of abandoned mine fund of PL 95-87.

Recommendations

During active mining operations acid mine drainage point discharges can be treated from surface and underground mines, coal storage piles, and refuse dumps to meet the EPA effluent limitations and thus minimize to an acceptable level the discharge of acidity, and heavy metals to streams. Enforcement of existing laws such as PL-92-500 and PL 95-87 should provide adequate control to prevent substantial increases in pollution from all sources except inactive underground. Further control technology development is required in this area.

In order to adequately address the subsidence problem a concerted effort is needed by all levels of government, Federal, State and local to coordinate the surface development with the extraction of the coal so that maximum use can be made of each resource. For a heavily built up area underlain by mineable coal, the subsidence control measures must be aimed at preventing

surface subsidence by controlling the mining operation to minimize surface disturbance. For nondeveloped areas the emphasis must be placed upon delaying surface development until the coal resource is extracted and the area has undergone subsidence and stabilized.

SECTION 2

ACID MINE DRAINAGE

CAUSE OF ACID MINE DRAINAGE

One of the most damaging waterborne contaminants from coal mining operations is the acid generated from the exposure of iron sulfide minerals found in the coal and overburden. Not only does the acid directly impact stream biota, eat away metal structures and destroy concrete, but as a result of the low pH, other ions such as heavy metals, become solubilized and carried into water courses. These ions are often toxic to aquatic life and render the water unusable for domestic and industrial use. In 1969 it was estimated that in excess of 10,000 miles of streams have been degraded by acid mine drainage[1]. This figure is surely less today as a result of treatment of acid mine drainage from active mines by industry and improved surface mining techniques.

The removal of overburden often exposes rock materials containing pyrite (iron disulfide). The oxidation of pyrite (FeS_2) results in the production of ferrous iron and sulfuric acid. A further reaction then proceeds to form ferric hydroxide and more acid. As noted in Table 2, the products of these various reactions are iron, sulfate, acid and the various heavy metals that may be associated with the host pyrite such as Cu, Zn, Al, and Mn.

TABLE 2 - TYPICAL ACID MINE DRAINAGE[b]

Parameter[a]	Mine #1	Mine #2	Parameter[a]	Mine #1
pH	5.0	2.8	As	0.01
Acidity, $CaCO_3$	640	470	B	0.5
Alkalinity, $CaCO_3$	17	0	Cd	<0.001
Ca, $CaCO_3$	370	210	Cr	0.05
Mg, $CaCO_3$	110	93	Hg	0.0003
Fe, Total	300	93	Cu	0.01
Fe, Ferrous	270	0	Ni	0.20
Na	480	2	Se	<0.001
Al	15	31	Zn	0.25
Mn	6	4	PO_4	8.6
SO_4	3040	610		
T.D.S.	4320	1050		
Conductivity	3760	1190		

(a) All units mg/l except pH and conductivity (micromhos/cm).
(b) In-house EPA data.

The amount, and rate of acid formation, and the quality of water discharged are a function of the amount and type of pyrite in the overburden rock, and coal, time of exposure, characteristics of the overburden, and amount of available water. Crystalline forms of pyritic material are less subject to weathering and oxidation than amorphic forms. Since oxidation is the primary reaction during early acid formation, the less time pyritic material is exposed to air, the less acid is formed. It has also been observed that even under ideal physical and chemical conditions for oxidation that the reactions do not proceed at their maximum rate immediately. If the overburden also contains alkaline material such as limestone, acid water may not be discharged even though it is formed, because of inplace neutralization by the alkaline material. Discharges from this situation are usually high in sulfate.

Enough water to satisfy the pyrite oxidation reaction is usually available in the overburden and coal material. Water also serves as the transport medium that removes oxidation products from the mining site into streams. Control of this water is a positive pollution preventative method.

Bacteria are almost always present in acid mine drainage. These bacteria obtain their energy for growth from the oxidation of reduced sulfur compounds and ferrous iron. Their role in pyrite oxidation is still under debate. They plan a significant role in the oxidation of ferrous iron to the ferric form. From an acid mine drainage control standpoint, the role of the bacteria is unimportant because 1) iron oxidizing bacteria are common in soils, etc. and thus the source cannot be controlled, 2) bactericides have not been shown to be effective, and 3) oxygen control impedes the reaction whether it is chemical or biological.

Acid mine drainage is a unique pollutant, because acid generation and discharges continue to occur after mining has ceased. The most comprehensive survey of the magnitude of acid mine drainage discharged was reported in '969. The results of this survey are shown in Table 3.

TABLE 3 - ACIDITY FIGURES FOR APPALACHIAN AREA COAL MINES(1)

Source	Acidity 1,000 lb/day	Percent
Underground, Active	614	19
Underground, Inactive	1,712	53
Surface, Active	28	01
Surface, Inactive	361	11
Combined, Active*	60	02
Combined, Inactive*	238	07
Other	245	07
	3,258	100

*Includes sources where underground could not be separated from surface.

As noted here underground mines contribute over 70 percent of the acid mine drainage. Inactive mines are also a major contributor.

The acid mine drainage problem is essentially a regional one. Most of the problem lies in the Appalachian Region (Table 4). Acid discharges are found in the Interior Region in the states of Indiana, Illinois and Western Kentucky. Except for some isolated situations, acid mine drainage is not a problem in the western states, because the coal and overburden have a low pyrite content and a high alkaline content.

TABLE 4 - DISTRIBUTION OF ACID MINE DRAINAGE PROBLEMS IN COAL PRODUCING STATES

State	Federal Region	Acid Mine Drainage	State	Federal Region	Acid Mine Drainage
Alabama	4	yes	New Mexico	6	no
Arizona	9	no	North Dakota	8	no
Arkansas	6	no	Ohio	5	yes
Colorado	8	no(a)	Oklahoma	6	no
Illinois	5	yes(b)	Pennsylvania	3	yes
Indiana	5	yes	Tennessee	4	yes
Iowa	7	no(a)	Texas	6	no
Kansas	7	no	Utah	8	no
Kentucky	4	yes(b)	Virginia	3	no
Maryland	3	yes	Washington	10	no
Missouri	7	no(a)	West Virginia	3	yes
Montana	8	no(a)	Wyoming	8	no

(a) Isolated cases of acid mine drainage have been reported.
(b) Large portions of coal fields do not have acid mine drainage problems.

EFFECTS OF ACID MINE DRAINAGE

The quantification of the impact of acid mine drainage in terms of dollars loss has never satisfactorily been accomplished. The major impacts are:

1. Aquatic life is destroyed and productivity reduced.

2. Water-based recreation is reduced.

3. Deleterious effects on industrial water users are incurred, manifested by high acidity, hardness, iron and manganese.

4. Municipal water supplies are impacted by acidity, iron, hardness, dissolved solids and manganese.

5. Highway and navigation facilities are impacted by increased corrosion of metal structures.

The Applachian Regional Commission study reported that in excess of 10,000 miles of streams have been degraded with acid mine drainage[1]. The majority has occurred in the Appalachian region. This figure undoubtedly is less today as a result of the treatment of mine drainage at active mines.

CONTROL OF ACID MINE DRAINAGE

Mines can be divided into two categories: surface and underground. Surface mines can further be divided into three basic types: (1) area mines, located on relatively flat land, usually less than 200 feet deep and covering large areas, (2) contour mines, found in mountain areas, usually less than 150 feet deep, narrow and long, and (3) pit mines, usually deep, often having a high coal-to-overburden ratio.

Treatment

Technology is available to neutralize the acid mine drainage discharged from mines[2]. The effluent guidelines established by EPA are based on the neutralization of acid mine drainage to meet the standards shown in Table 5. Although the water treated in this manner will have a satisfactory pH, acidity, iron and manganese for most uses, the water will still have a high hardness and dissolved solids content making it unsuitable for some uses. Except for a few situations, treatment is not considered a viable solution for inactive mines because of the long treatment period required, high costs and the unavailability of a responsible party. Reverse osmosis and ion exchange methods are available to treat acid mine drainage and produce a near potable water, but due to their high cost, they would only be used in special cases. Treatment is the usual control method employed at underground mines during active mining and in conjunction with preventative methods during active surface mining.

Underground Mines

Since acid formation has been found to be a result of the oxidation of pyrite, all acid mine drainage preventative technology is based on the reduction or elimination of the exposure of pyrite to air. Water serves as a transport media and a reactant in the oxidation process. Water control methods attack the transport phases and not the reactant phase, since sufficient water is available in the humid atmosphere of an underground mine to satisfy the oxidation process.

Air Control--

Ever since the 1920's, when it was documented that pyrite oxidation was the cause of acid mine drainage, attempts have been made to prevent air from entering underground mines[3]. The massive mine-sealing program of the 1930's is but one example. Air control has been accomplished basically by one of three methods: (1) sealing, plugging, filling, or closing off all portals, boreholes, openings, cracks, fissures, etc., to prevent air from entering the mine working; (2) filling the mine working with water as an oxygen barrier, and (3) filling the mine working with an oxygen-free atmosphere. All of these methods are only applicable to inactive mines or worked out portions of active mines.

The debate over the effectiveness of placing an air seal in mine portals and sealing known openings into an underground mine has been waged for years. It has been shown many times in laboratory studies that if oxygen is excluded from the mine, acid mine drainage formation will cease. The major problem lies in actually sealing an underground mine so that the oxygen level is reduced sufficiently to cause a significant decrease in acid formation. In most cases this cannot be accomplished because of the mine breathing through the cracks, fissures, and fractures in the overburden material. The effectiveness of a first-class, air-sealed mine--with all known openings, subsidences, and the like sealed--is about 50 percent. Mines with shallow cover, outcrops surface mined, and mines highly subsided would be less conducive to air sealing. An air-sealed mine requires maintenance to assure the integrity of the seal.

TABLE 5. EFFLUENT LIMITATIONS, IN MILLIGRAMS PER LITER EXCEPT FOR pH*[4]

Effluent Characteristic	Maximum Allowable	Average of Daily Values for 30 consecutive Discharge Days
Iron, total	7.0	3.5
Manganese, total	4.0	2.0
Total Suspended Solids	70.0	35.0
pH	6.0 to 9.0	----

*These limitations are currently being challenged in the courts.

Several investigators have noted that when pyrite is submerged under water, pyrite oxidation essentially ceases. Mines below drainage that are permanently flooded do not normally have an acid mine drainage problem. In recent years, efforts have been made to flood inactive mines above drainage by utilizing bulkhead seals. Bulkhead seals have been used with heads up to

35 feet. The effectiveness of this seal depends on the integrity of the outcrop, the amount of the mine working that is permanently flooded, and the soundness of the seal. Effectiveness has ranged from 100 percent, where there is no longer a discharge, to as low as zero--the latter when a working extended so close to the outcrop that a barrier could not be established.

Water Control--

The basic approach to water control methods is to prevent water from entering the mine working, where it could flush and transport the products of pyrite oxidation from the mine. These methods do not have a major effect on the pyrite oxidation process itself. Since it would be impractical and prohibitively expensive to prevent all water from entering the mine, only major water sources usually are controlled. Thus the method cannot be 100 percent effective.

Major sources of water directed to underground mines that can be controlled are: (1) streams that have been diverted into underground working or lost by way of subsidence holes, fractures, etc.; (2) surface mines that trap and direct water into underground mines, and (3) fractures, fissures, and cracks extending into the mine.

Common techniques used for water control are: (1) grading to facilitate rapid runoff away from the mine; (2) rechanneling of streams; (3) lining of streams; (4) filling and compaction of subsidence holes; (5) diversion ditches, and (6) sealing of boreholes, mine openings, fracture zones, and auger holes that allow water to enter the mine.

Another technique is aquifer control.

Aquifers above and adjacent to the mine are either drained by gravity or pumped through wells to dewater the mine. These techniques hold promise, and are now under study. If proven feasible they could be used for both active and inactive mines.

In summary, water control methods appear intuitively to be good ways to reduce acid mine drainage, but their effectiveness has not been well documented. A unit decrease in flow does not necessarily mean a unit decrease in acid load, because acid formation may not decrease. The only decrease may be the amount of acid flushed from the mine.

Filling and Removal--

Other approaches to the underground mine problem have included "fill-it-up," "knock-it-down," or "remove it."

"Fill-it-up" entails filling the voids within the mine. These methods are applicable to the inactive situation. Materials that have been suggested

as fillers are sand, coal refuse, fly ash, municipal waste, and waste residues such as sludges from acid mine drainage neutralization plants and SO_2 scrubbers. The major difficulty with filling any mine is moving material to the void. Most parts of an inactive mine are inaccessible by means of the passages cut during mining. Reopening these passages typically would be either impossible or prohibitively expensive. Thus, the only practical entry is through holes drilled from the surface. These holes are expensive, limit the size of the material that can be injected, and limit the distribution of the material as it enters the void.

In those situations where materials have been placed back into a mine, control of acid mine drainage has not been the purpose. The major effort has been to prevent subsidence or control mine fires. A combination of sand and coal refuse has been used in these situations, generally at high cost. The effect of mine filling on acid mine drainage control has never been determined.

Acid neutralization sludges and fly ash have been placed in underground mines as a means of disposing of waste residues, not for the purpose of controlling acid mine drainage. The materials, where they are alkaline, may neutralize acid water in the mine. They also may coat pyrite surfaces, thus preventing acid formation. On the other hand, there is a danger that the material will flow out a mine opening and, if the mine is very acid, that soluble salts will be leached from the residues. An additional problem is the large volume of residues required to fill a mine.

The "knock-it-down" concept has been proposed from two standpoints. The first is to blast the entire mine, causing it to collapse and thus filling all the voids. This method would have high cost and probably would result in surface damages. The blasting design and implementation to achieve complete collapse would be difficult because of the pillars, subsidence, and access to the mine voids. The second method is to blast alkaline overburden down into the mine voids. The premise is that as the acid water flows through the alkaline material, it would be neutralized.

The "remove it" concept also is referred to as "daylighting." Where the overburden depth is not too great, the underground mine is stripped out, using surface mining methods. Thus the remaining coal (frmom 25 to 60 percent) is recovered, and the underground mine is removed. The area then is reclaimed as a surface mine.

Surface Mines

All the techniques for preventing acid formation are based on the control of oxygen[5]. There are two mechanisms by which oxygen can be transported to pyrite--convective transport and molecular diffusion.

The major convection transport source is wind currents that can easily supply the oxygen requirement for pyrite oxidation at the spoil surface. In addition, wind currents against a steep slope provide sufficient pressure to drive oxygen deeper into the spoil mass. A factor to consider is the degree of slope after regrading. This is especially important on slopes subject to prevailing winds, since the wind pressure on the spoil surface increases as the slope increases. Thus, the depth of oxygen movement into the spoil would increase as the slope increases.

Molecular diffusion occurs whenever there is an oxygen concentration gradient between two points, e.g., the spoil surface and some point within the spoil. Molecular diffusion is applicable to any fluid system, either gaseous or liquid. Thus, oxygen will move from the air near the surface of the spoil, where the concentration is higher, to the gas or liquid-filled pores within the spoil, where it is lower. The rate of oxygen transfer is strongly dependent on the fluid phases and is generally much higher in gases than in liquids. For example, the diffusion of oxygen through air is approximately 10,000 times greater than through water. Therefore, even a thin layer of water (several millimeters) serves as a good oxygen barrier.

The most positive method of preventing acid generation is the installation of an oxygen barrier. Artificial barriers such as plastic films, bituminous, and concrete would be effective, but these have high original and maintenance costs and would be used only in special situations.

Surface sealants such as lime, gypsum, sodium silicate, and latex have been tried, but they too suffer from high cost, require repeated application, and have only marginal effectiveness. The two most effective barrier materials are soil, including nonacid spoil, and water. The minimum thickness of soil or nonacid spoil needed is a function of the soil's physical characteristics, soil compaction, moisture content and vegetative cover. Deeper layers would be needed for a sandy, dry granular material with large grain size and porosity than would be required for a tightly packed, moist clay that is essentially impermeable. Soil thickness should be designed on the basis of the worst situation--such as a dry soil where oxygen can move more readily through cracks and pore spaces devoid of water. A "safety factor" should be included to account for soil losses from such causes as erosion.

Water is an extremely effective barrier when the pyritic material is permanently covered. Allowing the pyrite to pass through cycles where it is exposed to oxidation and then covered with water will worsen the acid mine drainage problem. Water barriers should be designed to account for water losses such as evaporation and should include at least 30 centimeters (1 foot) of additional depth as a safety factor.

Additional measures to control acid mine drainage are water control and inplace neutralization. Water serves not only as the transport media that carries the acid pollutants from the pyrite reaction sites, but it erodes soil and nonacid spoils to expose pyrite to oxidation. Facilities such as diversion ditches that prevent water from entering the mining area and/or carry the water quickly through the area can significantly reduce the amount of water available to transport the acid products. Sediment and erosion control are needed both during and following mining. Terraces, mulches, vegetation, etc., used to reduce the erosive forces of water are effective measures to prevent further pyrite exposure. These measures usually are performed during reclamation.

Vegetation not only serves to control erosion, but after it dies, it becomes an oxygen user through the decomposing process. This further aids the effectiveness of the barrier. The organic matter that is formed also aids in holding moisture in the soil.

Alkaline overburden material and agricultural limestone can be blended with "hot" acidic material to cause inplace neutralization of the acid and assist in establishing vegetation. In some cases, grading directs acid seeps to drain through alkaline overburden. These techniques are more applicable to abandoned surface mines than to current mining, where proper overburden handling should prevent acid formation. The major exception may be those situations where an underground mine was breached and an acid discharge formed.

SUMMARY

During active mining operations acid mine drainage point discharges can be treated from surface and underground mines, coal storage piles, and refuse dumps to meet the EPA effluent limitations and thus minimize to an acceptable level the discharge of acidity, and heavy metals to streams. The water may still be unsatisfactory for some industrial and domestic uses because of its hardness and dissolved solids content.

The technology for controlling nonpoint acid mine drainage from surface mines is rather extensive. Current State Laws and the Federal Surface Mining Control and Reclamation Act of 1977, PL 95-87, provide regulations that will result in control of acid mine drainage both during and following mining. While acid mine drainage can be controlled (treated) during active underground mining, in most cases where the mine is above drainage and the water within the mine has free drainage, inadequate technology is available to close the mine to prevent acid mine discharges for extended periods of time (in excess of 100 years).

FEDERAL AND STATE CONTROL PROGRAMS

All point discharges from coal mines must have a discharge permit from a state or the U. S. Environmental Protection Agency. Criteria for these permits are presented in Table 5. To date in many states the issuance of these permits has lagged for the small mine and enforcement of permit requirements has not been extensive.

Of the 21 coal producing states, all but two have some form of a law to control environmental damages from surface mining. The degree of control afforded by these laws and regulations vary drastically from state to state. However, the passage of the Surface Mining Control and Reclamation Act of 1977, PL 95-87, on August 3, 1977, will result in federal environmental standards for the extraction of coal, both from surface mines and the surface effects of underground mines. These regulations will go into effect in February 1978. Many of the provisions of the Act and the subsequent regulations will result in the control of acid mine drainage. The Act under Section 515(a)(10) requires: "Minimize the disturbances to the prevailing hydrologic balance at the mine-site and in associated offsite areas and to the quality and quantity of water in surface and groundwater systems both during and after surface coal mining operations and during reclamation by--

Avoiding acid or other toxic mine drainage by such measures as, but not limited to--

1. preventing or removing water from contact with toxic-producing deposits;

2. treating drainage to reduce toxic content which adversely affects downstream water upon being released to water courses;

3. casing, sealing, or otherwise managing boreholes, shafts, and wells and keep acid or other toxic drainage from entering ground and surface waters."

The interim regulations propagated in November, 1977 provide the bases for a strong program to control acid mine drainage. Not only must water quality discharge standards be met, but specific mining methods and techniques must be employed that prevent the formation and discharge of acid. Thus, the regulations, if properly followed and enforced, should result in a significant reduction of acid discharge from active and inactive surface mines. State and federal laws for the control of acid discharges for inactive underground mines have not been enacted, although, PL 95-87 does establish an ABANDONED MINE RECLAMATION FUND which should result in the cleanup of numerous acid discharges.

EXTENT AND EFFECT OF ACID MINE DRAINAGE BY 1985 AND BEYOND

Table 6 presents the projections of the National Energy Plan (NEP) scenario. The NEP prescribes that its Annual Production of Coal will increase by 1985 by 4.1×10^{15} BTU over that produced without the plan. This increase will be met almost entirely from surface mines, in fact underground production will be less under the NEP than under the Pre-NEP scanario.

Since acid mine drainage is a problem only in Regions 3, 4 and 5, future increases in coal production will only impact the acid discharge in these areas. Acid mine drainage discharges occur from surface mines, mine waste, and underground mines. During active mining, the control of point discharges afforded under PL 92-500 and surface mines and mine waste under PL 95-87 should result in essentially no further discharges of acid to streams. In fact as the enforcement of these acts becomes better, acid discharges from currently operating mines should be eliminated. In addition, nonpoint source acid discharges from surface mines and mine waste should be controlled under the regulations provided under PL 95-87. Thus, only underground mine acid discharges that occur after the mine is closed will increase between 1977 and 1985 and beyond, because technology to control this problem is not available. A projection of these increases is presented in Table 7. By 1985, the level of acid discharges under Pre-NEP and NEP should be similar, because the increase in discharges will be a result of the closing of currently active mines, but not new mines, since the lag time to open an underground mine and the mine life will place its closure after 1985. The impact will almost entirely be felt in Region 3, because it is in this Region that acid-producing drift mines predominate. The full impact of the new mines will not be felt until their closure.

TABLE 6 - ANNUAL PRODUCTION OF COAL IN 10^{15} BTU[6]

	Scenario	
	Pre-NEP	NEP
Underground		
1975	7.3	7.3
1985	10.8	9.8
2000	13.3	15.7
Surface		
1975	7.9	7.9
1985	13.2	18.3
2000	24.7	29.2
Total		
1975	15.2	15.2
1985	24.0	28.1
2000	38.0	44.9

NEP - Projection based on President's National Energy Plan, April 29, 1977.
Pre-NEP - Trend based on projections prior to NEP.

TABLE 7 - SULFATE RELEASES ASSOCIATED WITH EASTERN UNDERGROUND MINING*[6]

10^3 Tons

Region	1975	1985	2000	%Increase 1975-2000
3	720	836	1,000	38
4	40	45	94	135
5	21	29	45	114
Total	781	910	1,139	45

*Sulfate is an indicator of acid production.

TABLE 8 - INCREASE OF ACID MINE DRAINAGE OVER 1975 LEVELS (PERCENT)

	1985		2000	
	Pre-NEP	NEP	Pre-NEP	NEP
Surface Mine				
Point Source	0(a)	0(a)	0(a)	0(a)
Nonpoint Source	0(a)	0(a)	0(a)	0(a)
Mine Waste				
Point Source	0(a)	0(a)	0(a)	0(a)
Nonpoint Source	0(a)	0(a)	0(a)	0(a)
Underground Mines				
Point Source	0	0	0	0
Nonpoint Source(b)	16	16	10(c)	13(c)

(a) May be a decrease as a result of PL 92-500 and PL 95-87.
(b) Includes inactive mines.
(c) Reflects impact of abandoned mine fund PL 95-87.

By the year 2000, the increase of acid resulting from the increase in the inactive draft mines will be counter-balanced by the decrease in acid results from the abandoned mine reclamation program provided for in PL 95-87. In addition more mining will be at deeper depths, which do not produce acid mine drainage upon closure.

SECTION 3

SUBSIDENCE

CAUSE AND EFFECT OF SURFACE SUBSIDENCE

The mining of a substantial quantity of underground material such as coal creates a void which in turn often produces a condition of instability within the rock leading to collapse of the overlying rock into the void and frequently associated surface subsidence. Subsidence begins as soon as the supports or pillars left in the mine are no longer able to support the overburden weight. This condition may occur during the conduct of the mining operation or may not occur until many years after mining has been completed and the pillars slowly decay to the critical failure point. Once the overlying material falls into the mine void, then cracking and caving proceed upward over a finite period of time often reaching the surface and causing considerable damage.

Earth movements at the surface may result in many varied types of damage. Buildings are more severely affected by the compressive and extensive strains associated with subsidence than they are by the actual settlement. Highways, bridges, water and gas lines may be sheared, twisted or broken by strains and slope changes produced by subsidence. Sewage lines are especially susceptible to changes of slope that locally reverse their direction of flow. Effects upon the natural environment can also be quite dramatic. Natural drainage patterns can be changed resulting in formation or occasional destruction or swamps. Surface streams often are intercepted by subsided areas or induced rock fractures resulting in flow into deep mines and loss of surface waters. In severe cases groundwater supplies may be intercepted and drained into underlying deep mines. Mine subsidence produces a significant deterioration of both the natural environment and manmade structures.

No definitive national analysis of the amount of land affected by past mine subsidence or of the annual or total property damage has been made. However, an appreciation of the magnitude of the problem can be gained from the experience of the Coal and Clay Mine Insurance Fund of the Commonwealth of Pennsylvania. Although only a small portion of undermined and developed land in Pennsylvania is insured (about 7,500 policies in effect) nearly one million dollars is paid out annually in damage claims[7]. Approximately 2,800 separate subsidence incidents involving damage have been reported for the anthracite fields of Pennsylvania alone[8]. The U. S. Bureau of Mines has estimated subsidence costs, both surface damage and control costs, for a twelve county area in Western Pennsylvania for the year 1968. Total surface damages from active underground mining of coal for this twelve county area were estimated at $295,000 with an additional $4.3 million of coal left in place to minimize potential surface damage[9]. These figures would be much higher under current economic conditions.

Many interrelated factors influence surface subsidence and the rate at which subsidence occurs in a particular location. Figure 1 illustrates some of the major geological and mining conditions that are related to initial underground mine roof failures and resulting subsidence[10]. Once roof failure has occurred many interrelated factors such as intensity and depth of mining, type and amount of roof support provided, composition, thickness and number of coal beds mined, composition, thickness and degree of consolidation of the overburden and structural features such as steepness of dip of the coal beds and presence of planes of weakness within the rock strata all affect the amount and rate of subsidence. These factors are summarized in Figure 2.

Each instance of subsidence is unique because the many interrelated factors listed above can be varied individually and combined in a variety of ways. Although the surface appearance of subsidence features can vary greatly, occurrences can generally be classified as pothole, linear or regional as defined in Table 9.

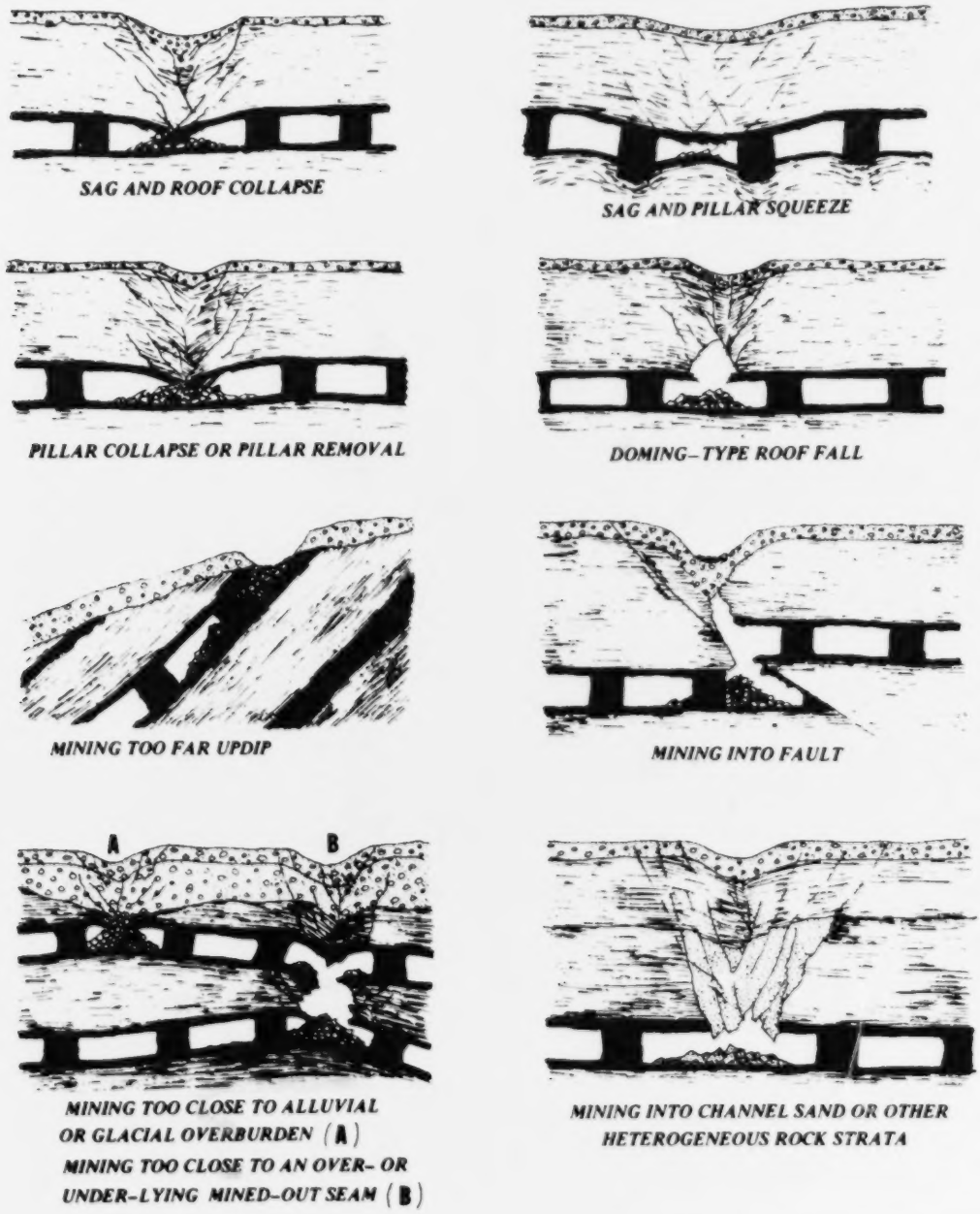
SAG AND ROOF COLLAPSE
SAG AND PILLAR SQUEEZE
PILLAR COLLAPSE OR PILLAR REMOVAL
DOMING–TYPE ROOF FALL
MINING TOO FAR UPDIP
MINING INTO FAULT
A
B
MINING TOO CLOSE TO ALLUVIAL OR GLACIAL OVERBURDEN (A)
MINING TOO CLOSE TO AN OVER- OR UNDER-LYING MINED-OUT SEAM (B)
MINING INTO CHANNEL SAND OR OTHER HETEROGENEOUS ROCK STRATA

Figure 1. Geological and Mining Conditions Related to Underground Roof Failures and Resulting Surface Subsidence[10]

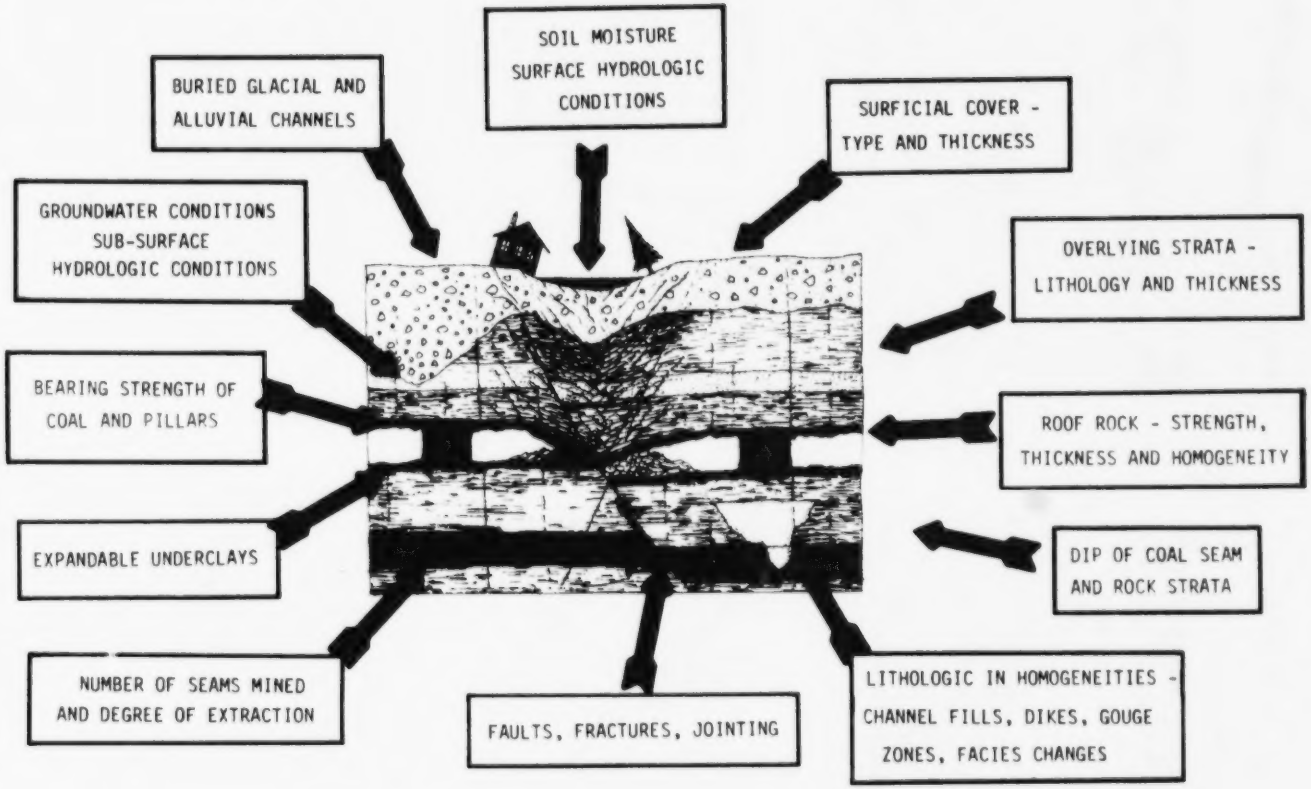

Figure 2. Factors Affecting the Amount and Rate of Surface Subsidence[10]

TABLE 9 - SURFACE SUBSIDENCE CLASSIFICATION AND MORPHOLOGICAL CHARACTERISTICS[10]

Type	Pattern	Surficial Characteristics	Width/Depth Ratio	Geological Character
Pothole Subsidence	Single features	Single circular or rectangular depressions	Ranges from 1:1 for new to 5:1 for stabilized potholes	Thick overburden
	Alignments	Linear series of discrete circular or rectangular depressions		Various bedrock attitudes (0°-90°)
	Lattice	Network of closely spaced potholes		
Linear Subsidence	En echelon to curvilinear	"Torn" appearance of bedrock cracks	Much deeper than wide. Range of 1:2 to 1:10+	Thin overburden horizontal to gently dipping bedrock
	Joint-controlled	Relatively smooth bedrock breakage along joint planes		
	Interconnected	Formed by the connection of several potholes in a line, usually along an outcrop.		Moderate to steep dips
Regional Subsidence	Irregular to circular or rectangular shaped moist areas or dry depressions	Large (greater than 1 acre) swampy or water-filled areas differentiated from natural features by age. Criteria includes tree stump remnants, chaotic vegetation assemblages and evidence from historical photography.	Much wider than deep; large areal subsidence. Vertical subsidence ranges from 1 to 10 feet	Thick overburden, common in alluvial valleys. Horizontal to gently dipping strata

CONTROLLING THE CAUSE AND EFFECTS OF SUBSIDENCE

Although there is no simple or universal solution to all of the problems caused by subsidence, various means are available to control surface damages[11] from future mining. Two basic approaches must be coordinated and applied to each situation. The first approach involves controlling the mining activity while the second involves controlling the nature of surface development. The specific subsidence damage control measures most suitable depend upon the extent of surface development that would be threatened by subsidence. For a heavily built up area underlain by mineable coal, the subsidence control measures must be aimed at preventing surface subsidence by controlling the mining operation to minimize surface disturbance. For nondeveloped areas the emphasis must be placed upon delaying surface development until the coal resource is extracted and the area has undergone subsidence and stabilized.

Future mining of high and medium density development areas in a manner which would result in future subsidence could have a major economic impact which would be unacceptable in terms of both individual impact and impact on the general welfare of the community[12]. Such damage can occur, however, if the right of surface support is not held by the surface development owner, or if proper enforcement of regulations relative to mining techniques is not achieved in those areas where surface support may be required[12]. Mining technology presently exists which would generally permit recovery of approximately 50 percent of the coal while substantially reducing surface subsidence.

Conventional room and pillar mining can be modified to provide surface support in many cases by accepting much lowered extraction ratios with careful attention to design, size and spacing of support pillars. This method has been used successfully in Western Pennsylvania where present law requires the mine operator to provide surface support for some structures. Panel and pillar mining likewise can be adapted to minimize subsidence damage and is compatible with longwall mining[13]. Shortwall mining techniques can also be adapted to provide surface support[13]. The critical considerations in utilizing these methods involve abandonment of adequate coal for support (about 50%), adequate pillar size so that deterioration of pillars will not cause subsidence and careful design of pillar placement to support the overburden. Other techniques have been proposed to reduce the impact of subsidence by minimizing the compressive and extensive strains that do most of the damage. These methods include extraction face control measures to control the propagation rate of the subsidence trough and harmonious extraction methods based on the principal of overlapping compressive and extensive strains to achieve a cancellation effect[14]. In addition, various backfilling measures such as hand packing, mechanical backfilling, hydraulic backfilling and pneumatic backfilling can be utilized to reduce the amount of surface subsidence[15]. Although backfilling may appear to be an attractice subsidence control measure,

the high costs involved, at least one to four dollars per ton of coal mined under favorable conditions[16], pose a serious question of economic viability.

Although methods exist to permit mining of a portion of the coal under developed areas without inducing subsidence, it is not likely that mine operators will voluntarily abandon a large percentage of their mineral resource unless they are required to provide surface support. The key to the problem is the recognition that land ownership and rights can be divided into three estates: surface rights, mineral rights, and surface support rights[12]. Each of these three estates or rights can be held in separate ownership. Unless the surface property owner is assured the right of surface support it is likely that future mining under developed areas will produce substantial damage similar to that which has occurred in the past. If the mine operator must provide surface support then approximately 50 percent of the mineral must be abandoned which raises a key policy issue in terms of meeting the Nation's energy needs.

For situations where mineable coal exists under sparcely or undeveloped areas the solution is simpler in concept but may prove equally difficult to implement. Future development of these areas should be controlled to preclude high or medium density development which may be subjected to future subsidence. It is recommended that prior to approval of any surface development in areas underlain by coal (or other deep mineable mineral) that the potential for future mining and subsequent subsidence be reviewed. In cases where the right to surface support has been separated from the surface ownership a potential threat to life and property exists if development occurs prior to mining. Therefore, it is suggested that in areas where mineral rights have been severed from the property rights the property owner should be required to certify the specific status of the rights to surface support prior to subdivision or land development for which any state or local permit may be required. Further, if the right to surface support is not held by the property owner and deep mining of the area is likely then the permit for such surface development may be denied[17].

Just as it is impractical to allow development to occur in areas where future mining may present a real threat of subsidence it is equally impractical to consider that mining should be allowed to occur in a manner that the resultant subsidence potential is of a nature which cannot be defined in terms of time and extent. Regulation of the mining industry should be established which will avoid the creation of a potential subsidence problem which will incumber the subsequent surface use of land for extended or indeterminate periods of time. The principal problem presented with regulation of development in such cases is that it is impossible to predict (based on current and projected data) when subsidence may occur. This precludes development of the land for an extended period unless very expensive stabilization measures are implemented. Two general approaches to mining techniques should be considered[17].

1. Mine in a manner that will not cause immediate or long-term subsidence problems.

2. Mine in a manner which would result in immediate and complete subsidence.

Under the first approach it would probably be necessary to limit extraction to 50 percent or less, based on current generally accepted engineering principals. Under the second approach of total extraction or near total extraction, it would be necessary to insure that the surface is left in or returned to a usable state. Flexibility in such regulation must, however, be maintained since physical problems may exist which would preclude implementation that would achieve the desired result. Trade-off and alternative approaches must be accommodated to effectively deal with individual case situations[17].

FEDERAL AND STATE PROGRAMS TO CONTROL SUBSIDENCE

If no actions are taken by the Federal or State governments to control subsidence problems from future mining, then it is likely that present problems will be compounded and eventually remedial action will become necessary by government agencies. A 1976 U. S. Bureau of Mines report indicated that four backfilling demonstration projects were currently in progress for abandoned mine subsidence control with an estimated cost of seven million dollars[18]. The U. S. Bureau of Mines estimates that it will be involved in 3 to 5 subsidence control projects (for abandoned mines) per year for the next 5 to 10 years[18]. Presently there is no federal program to control creation of future subsidence problems. Only one state, Pennsylvania, has enacted legislation specifying the separate responsibilities of surface owners and mine operators for subsidence damage[19]. Under Pennsylvania law, which applies only to the bituminous fields, a mine operator is responsible for damage to surface structures that were in existence prior to implementation of the law (1966). Surface structures built after 1966 in subsidence-prone areas can be protected by purchasing coal support from the mine operator. Generally the practice of conveying ownership of minerals separate from surface ownership with the right to extract the mineral regardless of surface effects has placed the cost of repairing subsidence damage upon the surface owner.

The new surface mining law, Public Law 95-87, of August 3, 1977, addressed the subsidence problem in a general manner under Section 516(b)(1) which states in part

> "Each permit issued under any approved State or Federal program pursuant to this Act and relating to underground coal mining shall require the operator to--

> adopt measures consistent with known technology in order to prevent subsidence causing material damage to the extent technologically and economically feasible, maximize mine stability, and maintain the value and reasonably foreseeable use of such surface lands except in those instances where the mining technology used requires planned subsidence in a predictable and controlled manner: Provided, that nothing in this subsection shall be construed to prohibit the standard method of room and pillar mining"

In order to adequately address the subsidence problem a concerted effort is needed by all levels of government, Federal, State and local to coordinate the surface development with the extraction of the coal so that maximum use can be made of each resource without conflicting with development of the other. The alternative of waiting until subsidence actually occurs before taking action would involve accepting extensive property damage and would negate many of the benefits that could be achieved by preventive action[20]. Subsidence occurring in critical areas could create conditions potentially injurious or fatal to local residents[19].

EXTENT OF POTENTIAL SUBSIDENCE BY 1985 AND BEYOND

The extent to which future mining will increase the subsidence problem depends upon the actions taken to prevent creation of future subsidence problems by coordinating surface development and mineral extraction activities. If no action is taken then the U. S. Bureau of Mines has estimated that by the year 2000 over 1.5 million acres of land will be affected by subsidence with resulting property damage of at least two billion dollars[21]. The energy shortage promises to even further aggravate subsidence problems as the demand for coal rapidly increases. Since the majority of our Nation's coal reserves can be mined only by underground methods, the potential for surface subsidence will become even greater, especially with the wider use of total coal extraction methods such as longwall mining[22].

To estimate the impact of subsidence from increased underground mining it is useful to examine future temporary land use demand for deep mining as an indicator of deep mining activity and thereby of subsidence potential. Table 10 provides an estimate of increasing land use for deep mining by the years 1985 and 2000. Assuming that increased land use parallels increased deep mining activity and that subsidence from future mining follows the pattern from past mining, then annual increases in subsidence of 22 percent for Region 3, 9 percent for Region 4, and 42 for Region 5 may be expected by 1985. Likewise increases of 48 percent for Region 3, 141 percent for Region 4

and 121 percent for Region 5 may be expected by the year 2000. The major impact will be in the major coal-producing states indicated in Table 10. A similar projection can be made from Table 11 which presents estimates of increased coal production from underground mining for the years 1985 and 2000 including the estimated effect of the President's National Energy Plan (NEP). Assuming subsidence parallels the rate of underground coal production then subsidence occurrence by 1985 may increase by 48 percent without the NEP or 34 percent under the NEP. The reason for the smaller percentage increase under the NEP is due to the expected initial greater emphasis upon surface mining of coal, partly at the expense of underground mining, that would result under the NEP. By the year 2000 this initial emphasis on surface mining rather than underground mining will be overcome and increases in subsidence occurrences of 115 percent under the NEP and 82 percent without the NEP are estimated. These estimates are in general agreement with those for Regions 3, 4 and 5 based on the previous table. Subsidence from underground coal mining is expected to be negligible for other regions since underground coal mining is substantially confined to Regions 3, 4 and 5 and particularly to those states listed in Table 10. If effective coordination between underground coal mining and surface development is accomplished then these increases in subsidence and their associated effects can be substantially reduced but partly at the expense of reduced resource recovery.

TABLE 10 - ANNUAL TEMPORARY LAND USE ASSOCIATED WITH EASTERN UNDERGROUND MINING[6]

Region	10^3 Acres 1975	1985	2000	% Increase 1975-2000
3	65	79	96	48
4	34	37	82	141
5	19	27	42	121

Major coal-producing states within each region:
Region 3 - Virginia, West Virginia, Pennsylvania, and Maryland
Region 4 - Alabama, Tennessee, and Kentucky
Region 5 - Illinois, Ohio, and Indiana

TABLE 11 - ANNUAL PRODUCTION OF COAL IN 10^{15} BTU FROM UNDERGROUND COAL MINES[6]

	Pre-NEP	NEP
1975	7.3	7.3
1985	10.8	9.8
2000	13.3	15.7

NEP - Trends resulting from the President's National Energy Plan (4-29-77).
Pre-NEP - Trends without impact of NEP.

SECTION IV

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